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A Study on the Impact of Rainfall and Temperature on Rice Yield in Manipur During 1991-2024

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Abstract

The paper examines the effects of key climatic factors, specifically seasonal rainfall during the winter, pre-monsoon, monsoon, and post-monsoon periods, as well as maximum and minimum average temperatures, on rice yields from 1991 to 2024 in Manipur, located in Northeast India. The study observes a statistically significant downward trend in Total Annual Rainfall (TAR), primarily attributed to a substantial reduction in rainfall during the monsoon season. While there are no prominent long-term trends in seasonal rainfall, considerable variability exists from year to year. The decrease in monsoon rainfall volume is offset by an increased contribution of precipitation from the Pre-monsoon and Winter seasons, which are particularly erratic and unreliable. A considerable number of years have experienced scanty rainfall. Correlation analysis indicates that heightened rainfall during the Winter, Pre-monsoon, and Monsoon seasons is significantly linked to reduced rice yields. A statistical model reveals that monsoon rainfall serves as a significant negative predictor of yield. Conversely, maximum temperature is identified as a crucial positive predictor of yield. The minimum temperature was also recognised as a predictor, exhibiting a marginally significant negative correlation with yield. These findings underscore the importance of monsoon patterns and variations in day-to-night temperatures, particularly the increase in night-time temperatures, as critical climatic factors affecting rice productivity. This insight is essential for formulating effective agricultural adaptation strategies and targeted management of water resources.

Keywords: Climatic factors, seasonal rainfall, average temperature, yield and variability

Introduction

Indian agriculture is predominantly reliant on the vagaries of monsoon rainfall. Climate change has emerged as a serious issue in contemporary Indian agriculture, as farmers across numerous areas are finding it increasingly difficult to adapt to shifting temperature and rainfall patterns (Roy et al. 2021). Climatic conditions have a profound impact on crop production, particularly on the Kharif rice crop, which is one of the most common food crops in India and is vulnerable to fluctuations in annual rainfall and temperature. The rice crop serves not only as the primary food source but also as the principal agricultural output, thereby playing a crucial role in India's food security and rural economy (Das et al., 2020;

Gogoi et al., 2022). Understanding the relationship between seasonal weather changes and rice yield is vital for agricultural planning and food security (Patra & Mishra, 2019). Numerous studies across India have highlighted that variations in monsoon onset, duration, and intensity can drastically alter rice productivity patterns (Rathore et al., 2020). Climatic conditions are increasingly impacting the ultimate harvest results, while factors such as seed variety, fertiliser use, and farming practices are also essential (Kumar & Bhatia, 2022; Choudhury et al., 2023).

The amount and timing of the southwest monsoon rainfall are essential factors influencing rice yield in Manipur, a northeastern state of India (Singh & Devi, 2022; Das et al., 2020). The total water requirement for the entire season can range from 750 mm to 2500 mm, depending on the specific needs of the variety and location (Patra & Mishra, 2019; Rao et al., 2018). The average annual rainfall in Manipur ranges from 1250 mm to 2700 mm, which is sufficient for rice cultivation, although the range varies by location. Adequate and timely rainfall during critical growth phases is crucial for successful harvest. Rainfall in June is particularly essential for the effective germination, transplanting, and initial growth of the rice crop (Das & Hazarika, 2021). Research indicates a positive and significant relationship, suggesting that an increase in June rainfall is correlated with a rise in Kharif rice yield.

Additionally, rainfall in August and September is positively associated with yield, supporting the crop during the vital reproductive and grain-filling periods (Kumar & Bhatia, 2022; Singh et al., 2023). Irregular rainfall patterns, which encompass deficits such as drought conditions and excessive downpours or floods, present considerable risks to rice production. Inadequate or delayed monsoon rains lead to water stress, crop failures, and reduced yields, as most farmers rely on rainfall. Conversely, heavy or excessive rain, especially in July, can adversely affect yield, although this impact may sometimes be statistically insignificant, likely due to flooding, waterlogging, or interruptions to farming practices (Devi et al., 2020; Singh & Thokchom, 2023). Therefore, while moderate rainfall during the late monsoon months benefits yield formation, both deficit and surplus rainfall remain critical challenges for sustaining stable rice productivity in Manipur's rainfed systems (Gogoi et al., 2022; Kumar et al., 2021).

Temperature is a crucial climatic factor that affects rice physiology and yield (Krishnan et al., 2011; Kumar & Bhatia, 2022). Manipur has experienced a consistent increase in average annual temperatures, which is expected to persist, particularly in minimum and maximum temperatures, negatively impacting crop productivity (Devi & Sharma, 2021; Gogoi et al., 2022). Excessively high temperatures, particularly during critical stages such as ripening, can greatly affect the crop. Studies indicate that a rise in minimum (night-time) temperatures can decrease rice yield by increasing spikelet sterility and disrupting grain formation (Peng et al., 2004; Das & Hazarika, 2021). The combined impact of rising temperatures and unpredictable rainfall is heightening the vulnerability of the agricultural sector in Manipur, making it essential for farmers to adopt climate-resilient technologies and high-yielding varieties (HYVs) to reduce potential losses (Devi et al., 2020; Singh & Devi, 2022). These compounded stresses underscore the urgent need to adopt climate-resilient technologies, improve irrigation management, and utilise high-yielding, heat-tolerant rice varieties (HYVs) to safeguard food security and sustain rural livelihoods under changing climatic conditions (Lalrinsanga & Mishra, 2021; Kumar et al., 2021).

Given the impact of climate change, which is altering precipitation patterns and temperature conditions across Northeast India, a focused analysis of these dynamics is essential. This paper investigates the correlation between rice yield and climatic factors in Manipur, utilising historical data from 1991 to 2024. In particular, it seeks to address the issue of varying seasonal rainfall patterns and temperature fluctuations that affect the annual rice yield in the state.

Objective of the study

The main objective of the study is to examine the impact of rainfall and temperature on rice yield in Manipur during 1991-2024

Materials and Methods

Study Area

The present investigation focuses on the state of Manipur, situated in the northeastern part of India, positioned between latitudes 23°83′-25°68′ N and longitudes 93°03′-94°78′ E. This region is characterised by a predominantly subtropical monsoon climate, which receives abundant rainfall from the Southwest Monsoon from June to September (Manglem, A. 2024). Most part of the landscape is mountainous, featuring an intermontane valley at its core, where paddy farming is a prevalent practice. The economy and food security of the state are heavily reliant on monsoon precipitation, rendering it a crucial factor for agro-climatic research. The average annual temperature fluctuates between 16°C and 25°C, while the typical yearly rainfall ranges from 1400 to 2000 mm, influenced by altitude and orographic factors. Consequently, the study area serves as an excellent location for investigating rainfall variability and long-term climate patterns.

Data sources and analysis tools

The study is primarily based on seasonal rainfall and average temperature levels, drawing on secondary sources that cover the period from 1991 to 2024, specifically the Rainfall Statistics of India Series (India Meteorological Department), the Statistical Handbooks of Manipur, and the NER Data Bank. For trend analysis, seasonal and annual totals were calculated using two standard non-parametric methods: the Mann-Kendall Test, which identifies the presence of a monotonically increasing or decreasing trend in the time series, and Sen's Slope Estimator, which measures the magnitude of the trend while being robust to outliers and missing data. Both methods were performed in Python, utilising statistical libraries. Further, descriptive statistics, including the mean, coefficient of variation (CV), and percentage analysis, were employed to assess the variability of rice yield and climatic variables. Finally, multiple regression analysis was performed to evaluate the extent to which the independent covariates influenced the dependent variable, rice yield.

Variables Specification

The quantitative assessment analyses the dependent variable, yield, by examining its correlation with climatic factors using multiple regression analysis to determine the functional relationship between them. It is to estimate and forecast the average output level, based on the known or fixed values of the explanatory variables (Singh et al., 2016). The dependent variable is the annual rice yield, quantified in thousand metric tonnes. Conversely, the explanatory variables include seasonal rainfall during the winter, pre-monsoon, monsoon, and post-monsoon periods, as well as the average annual maximum and minimum temperatures.

Table 1: Variable Specification

Variable	Specification
Dependent Variable:	
1. Yield	in '000 metric tons
Independent Variable:	
1. Winter rain	in mm
2. Pre-Monsoon Rain	in mm
3. Monsoon Rain	in mm
4. Post Monsoon Rain	in mm
5. Average Maximum Temperature	in ^{0}C
6. Average Minimum Temperature	in ^{0}C

The model assumes a linear relationship between the dependent and independent variables, homoscedasticity of residuals, and the absence of multicollinearity among the predictors. The statistical significance of the coefficients was assessed using t-statistics, while the overall fit of the model was determined through the coefficient of determination (R^2) and F-statistics. Diagnostic tests were carried out to verify the validity of the regression assumptions, which included checking for multicollinearity using the Variance Inflation Factor (VIF) < 5, ensuring the normality of residuals, and confirming the absence of serial autocorrelation. The analysis was executed using Microsoft Excel and cross-validated with SPSS to ensure robustness.

Results and Discussion

Trends and Position of Rainfall

Decadal Rainfall Trends and Shifts in Seasonal Rainfall Share

The seasonal rainfall pattern in Manipur is substantially influenced by the southwest monsoon, which occurs from June to September, accounting for the bulk of the state's annual precipitation; however, notable local differences exist (Dash et al., 2012; Jain et al., 2013; Singh et al., 2016). The post-monsoon period (October-November-December) and the pre-monsoon period (March-May) experience a low quantum of rainfall, whereas the winter months (January-February) are generally arid (Kumar and Rajeevan, 2019; Das et al., 2021). Recent studies have indicated fluctuations and changes in these patterns, particularly after the year 2000 (Guhathakurta & Rajeevan, 2008; Pattanaik & Rajeevan, 2010; Lal et al., 2020). The analysis of rainfall data in Manipur from 1991 to 2024 reveals significant inter-annual and decadal variability, particularly concerning rainfall volume and seasonal distribution. The findings are presented in Table 2, which covers decadal trends and shifts in seasonal contributions. The data were categorised into three decadal periods to assess long-term changes.

Table 2: **Average Decadal and Seasonal Rainfall (mm) and Percentage Share**

Decadal Series	Decadal Average Rain (mm)	Winter Rain (%)	Pre-monsoon Rain (%)	Monsoon Rain (%)	Post-monsoon Rain (%)
1991-2000	1995.48	69.29 (3.47)	505.75 (25.34)	1259.47 (63.12)	160.97 (8.07)
2001-2010	1432.91	35.22 (2.46)	345.83 (24.13)	838.45 (58.51)	213.41 (14.89)
2011-2024	1522.55	33.41 (2.19)	373.46 (24.53)	900.74 (59.16)	214.94 (14.12)

The analysis reveals a considerably sustained shift in the hydro-climatic regime, characterised by a fundamental redistribution of precipitation across the defined seasonal boundaries, demonstrating a robust pattern of declining proportional contribution of the traditional core monsoon rainfall, compensated by a dramatic surge in the proportional contribution of the post-monsoon season. The results indicate a declining trend in total decadal average rainfall from 1995.48 mm during 1991-2000 to 1432.91 mm during 2001-2010, followed by a partial recovery to 1522.55 mm in 2011-2020. The percentage contribution of each season to the total annual rainfall reveals underlying changes in the seasonal timing and intensity of precipitation. The most critical shift is the significant decline in the Monsoon season's relative contribution to the total rainfall. Its share dropped from dominating 63.12% of the annual rainfall in the 1990s to 58.51% to 59.16% in the recent period from 2001 to 2010, and then to 2011-2024. This signals a fundamental change in the state's hydrological cycle (Deka et al., 2013; Halder et al., 2024).

The monsoon season contributes the highest share of annual rainfall across all decades, accounting for about 63.12% in 1991-2000, 58.51% in 2001-2010, and 59.16% in 2011-2024. A slight reduction in monsoon contribution after 2000 suggests increased variability and possible weakening of the monsoon system. The pre-monsoon rainfall contribution shows relative stability, ranging from 24.13% to 25.34%, indicating its consistent role in total annual precipitation. Conversely, winter rainfall remains minimal (2.19-3.47%) throughout, while post-monsoon rainfall doubles from 8.07% in 1991-2000 to around 14% in subsequent decades. Overall, the data reveal a decreasing rainfall trend during 2001-2010 with a moderate recovery in the following decade, suggesting inter-decadal fluctuations possibly linked to regional climatic variability and changes in monsoon dynamics.

This indicates that a larger proportion of the annual rainfall is now occurring earlier in the year (Choudhury et al., 2023; Das & Nath, 2021). This could imply an advance in the onset of rainy weather or a greater intensity of pre-monsoon convective activity, potentially affecting agricultural planning traditionally tied to the Monsoon season (Guhathakurta & Rajeevan, 2008; Bordoloi et al., 2020). While the absolute amount of rainfall is decreasing, the redistribution suggests that water resource management strategies must adapt to a bimodal distribution where the Pre-monsoon season is becoming increasingly crucial for water harvesting and irrigation planning (Chakraborty et al., 2025; Pathak et al., 2020).

Rainfall Trend Analysis

The analysis reveals high interannual variability in rainfall over the 34 years. Annual rainfall ranged from 573 mm (1994) to 2,995 mm (1991), with an average of approximately 1550 mm per year. The Monsoon season contributed nearly 70 % of the total annual rainfall. The Mann-Kendall test statistic ($Z = -1.57$, $p = 0.116$) indicates a weak, non-significant downward trend, supported by a negative Kendall's tau (-0.19). The Sen's slope of -15.43 mm/year suggests a gradual decline in annual rainfall over time. The long-term rainfall trend in Manipur (1991-2024) exhibits a weakly declining trend of approximately 15 mm per year. While statistically non-significant ($p > 0.05$), the consistent negative direction indicates possible early signs of climatic variability and a weakening monsoon pattern. However, the computed p-value (0.116) exceeds the 0.05 significance level, implying that the downward trend is not statistically significant at the 95% confidence level. Therefore, although rainfall shows a decreasing tendency, the evidence is insufficient to confirm a significant monotonic decline during the study period.

Table 3: **Mann-Kendall Test and Sen's Slope Estimate Results**

Mann-Kendall Test	Sen's slope estimate
S = -107	Sen's slope (β) = -15.43 mm per year
Var (S) = 4550.33	Intercept = 32359.79
	Trend equation:
Z = -1.57	Rainfall = 32359.79-15.43 × Year
p-value = 0.116	
Kendall's τ = -0.19	

Although the decreasing trend is not statistically significant, its persistence indicates potential early signs of rainfall decline in Manipur. The high inter-annual variability, characterised by alternating wet and dry years, likely obscures the long-term signal. Such rainfall fluctuations can substantially impact rice-based agriculture, the dominant cropping system in the region. Reduced monsoon intensity or delayed onset could affect transplanting schedules, yield stability, and irrigation planning. From a hydrological perspective, prolonged declines could also influence groundwater recharge and streamflow regimes. The observed tendencies are consistent with other studies in Northeast India, which have reported slight but non-significant decreases in monsoon rainfall over the past few decades (Das & Goswami, 2014; Guhathakurta et al., 2015). This coherence suggests that Manipur may be experiencing similar regional climatic shifts linked to ENSO events, Indian Ocean Dipole, and changes in monsoon circulation dynamics.

Annual and Seasonal Extreme Rainfall

Table 4 presents the highest and lowest rainfall years, as well as seasonal variations, across different periods. The results show that monsoon rainfall largely determines the total annual rainfall in Manipur, with 2994.7 mm and 2914.4 mm recorded in 1991 and 1993, respectively, as the highest yearly totals (Deka et al., 2013; Halder et al., 2024). Conversely, the years 1994 and 2003 experienced the lowest rainfall, at 573.3 mm and 687.7 mm, indicating deficient monsoon years (Choudhury et al., 2023). Winter rainfall contributes minimally to the annual total, with 1993 showing a seasonal maximum of 297.1 mm and 2004 recording only 1.3 mm (Bordoloi et al., 2020). The pre-monsoon and post-monsoon seasons also display considerable variability, with 1993 and 2019 exhibiting higher rainfall extremes, while 1994 consistently marks a dry year across all seasons (Das & Nath, 2021; Chakraborty et al., 2025). Overall, the data highlight a strong dependence on monsoon rainfall and significant interannual variability, reflecting the climatic sensitivity of Manipur's rainfall patterns (Guhathakurta & Rajeevan, 2008; Jain et al., 2023).

Table 4: **Annual and Seasonal Rainfall Extreme in Manipur during 1991-2024**

Rainfall Category	Year	Total Annual Rainfall (mm)	Seasonal Extreme (mm)	Season
Highest Annual Rainfall	1991	2994.7	1707.8	Monsoon
	1993	2914.4	1545.7	Monsoon
Lowest Annual Rainfall	1994	573.3	300.1	Monsoon
	2003	687.7	351.3	Monsoon
Seasonal Maximum	1993	2914.4	297.1	Winter
Seasonal Minimum	2004	1084.2	1.3	Winter
Seasonal Maximum	1993	2914.4	879.8	Pre-monsoon
Seasonal Minimum	1994	573.3	198.4	Pre-monsoon
Seasonal Maximum	2019	1625	700.6	Post-monsoon
Seasonal Minimum	1994	573.3	26.7	Post-monsoon

Excess, Normal and Deficient Rainfall Frequency

The 34-year rainfall series (1991-2024) was classified based on the India Meteorological Department (IMD) standard, using the calculated Long Period Average (LPA) of approximately 1177.56 mm. The table illustrates the distribution of rainfall over 34 years, categorising each year into three rainfall conditions of excess, normal, and deficient, based on deviations from the long-term average (LPA). Firstly, 17 years (50%) of the study period experienced rainfall levels below 942 mm, which is less than -20% of the LPA, indicating that half of the period was characterised by rainfall deficiency and leaned towards drier conditions, or a recurring trend of inadequate precipitation (Deka et al., 2013; Halder et al., 2024; Choudhury et al., 2023). Such high frequencies of below-normal years are consistent with regional analyses that report increasing interannual variability and prolonged dry spells across Northeast India (Das & Nath, 2021; Jain et al., 2023; Guhathakurta & Rajeevan, 2008).

Table 5: Rainfall classification based on long-period average and total annual rainfall

Rainfall Classification	Criteria (Relative to LPA)	Number of Years (1991-2024)	Frequency (%)
Excess	Less than 20% and above LPA (TAR greater than 1413 mm)	7	20.6%
Normal	-19% to + 19% of LPA (TAR 942 mm to 1413 mm)	10	29.4%
Deficient	Less than - 20% of LPA (TAR less than 942 mm)	17	50.0%
Total		34	100%

Such extended periods of deficient rainfall can significantly impact agriculture, water availability, and the sustainability of ecosystems (Chakraborty et al., 2025; Datta et al., 2022). Approximately 10 years (29.4%) fell within the deviation range of -19% to +19% from the LPA (942-1413 mm). These years demonstrated stable or average rainfall conditions, thereby supporting consistent agricultural productivity and preserving a hydrological balance (Halder et al., 2024). Nevertheless, the relatively low percentage of normal years, which is less than one-third of the total, highlights the instability and inconsistency of rainfall across the decades (Jhajharia et al., 2012; Das et al., 2020). It is noted that 7 years (20.6%) experienced above-normal rainfall exceeding 1413 mm. This analysis confirms the subjective observation from Table 7, which shows a decadal average trend of drying (Choudhury et al., 2023; Halder et al., 2024). Since 2001, the system has experienced a persistent rainfall deficit (Chakraborty et al., 2025). The classification demonstrates a critical shift in the climate regime. The traditional notion of a balanced distribution between Excess, Normal, and Deficient years is no longer valid. The high frequency of deficient years places severe stress on the region's largely rain-fed agricultural system and water resources, leading to increased risk of drought conditions (Datta et al., 2022; Goswami et al., 2006). The data indicate that adaptation strategies must prioritise managing water scarcity and drought resilience, as half of the years will likely fail to meet the historical Long Period rainfall Average (Das et al., 2020; Rao et al., 2023).

Descriptive statistics of Seasonal rainfall and temperature

Table 6 shows that the average winter rainfall dropped sharply from 70.05 mm to 35.25 mm (49.72%). The CV increased significantly (97.15%), showing high instability in winter rain (Choudhury et al., 2019; Singh & Jain, 2021). This reduction may impact soil moisture retention and early crop establishment. Pre-monsoon average rainfall decreased from 496.94 mm to 370.87 mm (25.37%), indicating a weaker pre-monsoon system, which may have affected land preparation and early sowing (Dash et al., 2012; Krishnan et al., 2020). The average monsoon rainfall declined from 1267.78 mm to 887.18 mm (-30.04%) (Chaturvedi et al., 2019). As the primary water source for rice cultivation, this reduction has significant implications for water availability during the peak growth period. However, the reduced variability, as shown by the CV (29.64 to 31.99, 7.94%), indicates relatively stable but lower rainfall. In contrast, post-monsoon average rainfall increased slightly from 163.53 mm to

211.94 mm (29.17%), which may partially compensate for the reduced monsoon rain, supporting late-season water availability (Rao et al., 2020; Singh et al., 2022).

Table 6: **Seasonal rainfall and temperature in Manipur during 1991-99 and 2000-24**

Seasonal Rainfall & Temperature	Descriptive Statistics	Period-I (1991-99)	Period-II (2000-24)	Percentage change
Winter rain (in mm)	Mean	70.08	35.28	-49.65
	CV	120.40	72.86	-39.49
Pre-monsoon rain (in mm)	Mean	496.94	370.87	-25.37
	CV	43.81	37.00	-15.55
Monsoon rain (in mm)	Mean	1267.78	887.18	-30.02
	CV	29.64	31.99	7.94
Post-monsoon rain (in mm)	Mean	163.53	211.24	29.17
	CV	70.03	67.93	-3.00
Average max. Temperature (^{O}C)	Mean	28.92	29.30	1.32
	CV	2.17	4.45	104.84
Average min. Temperature (^{O}C)	Mean	21.99	21.25	-3.35
	CV	3.37	6.64	97.12

Moreover, the redistribution of rainfall, characterised by diminished monsoon precipitation and a rise in post-monsoon rainfall, implies temporal shifts in water availability (Chakraborty et al., 2025; Halder et al., 2024). Despite these adverse climatic trends, the sustained and enhanced rice yield highlights the effectiveness of adaptive measures, including irrigation expansion and improved crop management, in mitigating the impacts of climatic variability on rice production (Ray et al., 2022; Datta et al., 2022; Pathak et al., 2020). Overall, these findings demonstrate a shifting rainfall regime in Manipur, characterised by declining winter, pre-monsoon, and monsoon precipitation, partially offset by an increase in post-monsoon rainfall (Deka et al., 2013; Choudhury et al., 2023). Such changes could significantly influence rice-growing environments, particularly in rainfed lowlands where yield is closely tied to the timing and distribution of rainfall (Bordoloi et al., 2020; Singh et al., 20211).

Further, it reveals that the average maximum temperature level rose slightly from 28.92°C to 29.30°C (1.32%) and CV increased substantially from 2.17 to 4.45 (104.84%), highlighting greater temperature fluctuations in recent years. This could influence heat stress on crops, especially during critical growth stages. Following the same trend, the average minimum temperature level increased from 21.99°C to 21.25°C, representing a reduction of 3.35%. The CV nearly doubled from 3.37 to 6.64, with 97.1% indicating greater variability in night-time temperatures, showing an increasing trend. This could influence heat stress on crops, especially during critical growth stages (Pathak et al., 2011). It can be inferred that rice yield increased dramatically, despite a decline in rainfall and rising temperature levels, which is likely attributable to technological advancements, the adoption of improved rice varieties, and better agronomic management practices (Aggarwal et al., 2008; Pathak et al., 2011; Singh et al., 2020).

Variability in annual yield

The comparative analysis of rice yield, annual rainfall, and temperature is presented in Table 8, comparing the two periods: Period I (1991-1999) and Period II (2000-2024). This analysis indicates substantial agro-climatic transitions in the state. It displays changes in rice yield, annual rainfall, and temperature (maximum and minimum), along with corresponding means and coefficients of variation (CV), showing percentage changes between the two periods.

The average rice yield in Manipur increased markedly from 180.90 thousand metric tons in 1991-1999 to 420.00 thousand metric tons during 2000-24, representing a rise of 32.18%. Simultaneously, the coefficient of variation (CV) declined sharply from 36.34% to 16.50% (a reduction of 54.63%), indicating that yield variability became substantially more stable and consistent over time (Pathak et al., 2020; Ray et al., 2022). In contrast, the total annual average rainfall decreased from 1,998.33 mm (1991-99) to 1,504.58 mm (2000-24), representing a 24.71% drop. The CV of annual rainfall also decreased from 33.30% to 26.12%, with a 7.18% reduction, suggesting a notable decline not only in mean precipitation but also in rainfall variability (Choudhury et al., 2023; Halder et al., 2024). These findings point to a progressive shift towards a relatively drier and more stable climatic regime in Manipur from 2000 onwards, accompanied by improved and more dependable rice yields, reflecting the positive effects of agricultural adaptation strategies, including irrigation development, adoption of stress-tolerant varieties, and improved management practices (Datta et al., 2022; Bordoloi et al., 2020; Singh et al., 2021).

Table 8: Descriptive statistics of rice yield, annual rain and temperature during 1991-2024

Variables	Descriptive Statistics	Period-I (1991-99)	Period-II (2000-24)	Percentage change
Yield	Mean	180.90	420.00	132.18
(in ‘000 tons)	C. V	36.34	16.50	-54.63
Total annual rain	Mean	1998.33	1504.58	-24.71
(in mm)	C. V	33.30	26.12	-21.57
Maximum	Mean	28.92	29.30	1.32
Temperature (^{O}C)	C. V	2.17	4.45	104.84
Minimum	Mean	21.99	21.25	-3.35
Temperature (^{O}C)	C. V	3.37	6.64	97.12

These results align with and contribute to the existing literature on yield-climate relationships. For example, studies of Indian rice cultivation generally find that both rainfall amounts and rainfall variability are key determinants of rice yield and yield variability (Chand & Dhaliwal, 2024; Nath & Mandal, 2018). Chand & Dhaliwal (2024) demonstrate that, despite being a highly irrigated region, Punjab's monsoonal rainfall variability remains positively correlated with rice yields. The authors stress that even years with deficit rainfall impact yields through groundwater recharge effects. Similarly, Nath & Mandal (2018) demonstrated heterogeneous climatic impacts on rice yields across agro-climatic zones in Assam, finding that rainfall variability, in particular, harmed autumn and winter rice yields. In a broader context, it reveals a nonlinear relationship between monsoon rainfall and rice yield in India, with an optimal rainfall threshold of approximately 1,621 mm, beyond which yields decline, and deficits also reduce yields (Maiti et al. 2024).

Correlation Analysis Between Rice Yield and Climatic Factors

Table 9 presents the Pearson correlation coefficients, which measure the strength and direction of the linear relationship between variables. Rainfall and yield analysis reveal generally negative correlations between rice yield and rainfall in the winter (-0.30), pre-monsoon (-0.30), and monsoon (-0.37) seasons (Bordoloi et al., 2020; Choudhury et al., 2023). This suggests that increased rainfall in these seasons is weak and moderately associated with decreased rice yield, consistent with earlier findings that excessive or poorly distributed rainfall can lead to waterlogging, reduced solar radiation, and yield decline (Das & Nath, 2021; Pathak et al., 2020). Conversely, post-monsoon rain shows a weak positive correlation (0.12), indicating a negligible relationship (Ray et al., 2022).

A moderate positive correlation exists between maximum temperature and yield ($r = 0.43$), implying that higher daytime temperatures are associated with increased yields within the observed range (Mishra & Datta, 2019; Pathak et al., 2020; Ray et al., 2022). In contrast, the minimum temperature shows a weak negative correlation (-0.12), suggesting that higher night-time temperatures may be slightly unfavourable (Welch et al., 2010; Lobell et al., 2011; Singh et al., 2021).

Table 9: Correlation between rice yield, seasonal rainfall and average temperature levels

Variables	Rice Yield (in '000 tons)	Winter (in mm)	Pre-monsoon (in mm)	Monsoon (in mm)	Post-monsoon (in mm)	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)
Rice Yield	1						
Winter Rain	-0.30	1					
Pre-monsoon	-0.30	0.46	1				
Monsoon	-0.37	0.29	0.52	1			
Post-monsoon	0.12	0.07	-0.01	0.22	1		
Max temp	0.43	-0.04	-0.15	0.02	0.00	1	
Min temp	-0.12	0.03	0.08	0.18	-0.09	0.47	1

However, the table indicates that monsoon rain has a positive correlation with pre-monsoon rain ($r = 0.52$), and maximum and minimum temperatures are also significantly associated ($r = 0.47$). These interrelationships are vital as they can influence the regression model (Bordoloi et al., 2020; Choudhury et al., 2023). The descriptive analyses reveal pronounced interannual variability in seasonal rainfall, which is dominated by the monsoon season, accounting for more than 50% of the total annual precipitation (Deka et al., 2013; Das & Nath, 2021). The long-term temperature trend indicates a rise in both maximum and minimum temperatures, with night-time temperatures increasing more rapidly, resulting in a narrowing diurnal temperature range (Chakraborty et al., 2025; Halder et al., 2024; Singh et al., 2021).

The correlation analysis shows a negative association between rice yield and rainfall during most seasons, suggesting that excessive rainfall may lead to waterlogging, pest outbreaks, or nutrient loss (Bordoloi et al., 2020; Das & Nath, 2021; Pathak et al., 2020). Conversely, higher maximum temperatures are associated with improved yields, possibly due to enhanced photosynthetic activity during grain formation (Mishra & Datta, 2019; Ray et al., 2022).

Impact of annual rainfall and temperature on rice yield

A multiple regression analysis was performed to understand the combined effect of these climatic factors on yield (Pathak et al., 2020; Singh et al., 2021). The regression model has an R-squared value of 0.49, meaning that 49% of the variation in rice yield is explained by the six independent variables, including seasonal rainfall and maximum/minimum temperatures (Choudhury et al., 2023). The Adjusted R Square (0.37) accounts for the number of predictors and suggests a modest explanatory power for the model (Mishra & Datta, 2019). The overall model is significant, as indicated by the F-statistic of 4.25, which is substantial at $p < 0.05$ (Ray et al., 2022). The negative constant term (-784.30) occurs when all independent variables are zero. Winter and pre-monsoon rain have coefficients that are not statistically significant ($p = 0.15$ and 0.56), so we cannot confidently say they influence yield (Bordoloi et al., 2020; Das & Nath, 2021).

Table 10: Regression statistics of rice yield based on seasonal rainfall and average annual temperature

Multiple R	0.70			
R Square	0.49			
Adjusted R Square	0.37			
Standard Error	100.68			
F- value	4.25			
	Coefficients	Standard Error	t Stat	P-value
Intercept	-784.30	460.07	-1.70	0.10
Winter rain	-0.57	0.38	-1.49	0.15
Pre-monsoon	0.08	0.13	0.60	0.56
Monsoon	-0.13	0.06	-2.08	0.05
Post-monsoon	0.16	0.13	1.24	0.23
Max temp	64.77	17.35	3.73	0.00
Min temp	-30.98	15.66	-1.98	0.06

Monsoon rain has a significant negative coefficient (-0.13) and a p-value of 0.05. This confirms the correlation finding, indicating that for every unit increase in monsoon rainfall, rice yield decreases by 0.13 units, holding all other factors constant (Bordoloi et al., 2020;

Choudhury et al., 2023). This finding suggests that after reaching a specific limit, heightened monsoon rainfall may have adverse effects, potentially due to waterlogging, reduced solar radiation, or an increased occurrence of pests and diseases. Higher rainfall reduces the yield variability of rice, whereas an increase in temperature is expected to increase rice yield variability (Verma, 2019; Pathak et al., 2020). This could be due to waterlogging or pest proliferation in excessively wet conditions (Singh et al., 2021).

The post-monsoon rain shows a positive but statistically insignificant coefficient at p-value 0.23 (Das & Nath, 2021). The average maximum temperature level has a highly significant positive coefficient (64.77, $p = 0.00$). This suggests that increases in maximum temperature have a strong, positive effect on rice yield (Ray et al., 2022; Mishra & Datta, 2019). Minimum temperature has a negative coefficient (-30.98) that is marginally significant ($p = 0.06$). This aligns with the correlation, hinting that rising minimum (night-time) temperatures could be detrimental to yield, potentially by increasing respiration rates (Welch et al., 2010; Lobell et al., 2011).

Conclusions

Manipur perceived a rising trend in the average temperature level during the two study periods, 1991-1999 and 2000-2024. Similar temperature increase patterns have been reported across Northeastern India, consistent with global and national warming trends (Dash & Hunt, 2007; Kothawale et al., 2010; Krishnan et al., 2020). Monsoon rainfall is the most significant rainfall variable, exhibiting a negative relationship with rice yield. Other seasonal rainfalls do not show a statistically significant impact within this model. Temperature plays a critical and contrasting role. The maximum temperature is an essential positive driver of yield, while the minimum temperature tends to be a negative factor. This underscores the complex role of diurnal temperature variation. The climatic factors examined explain a substantial portion (49%) of the yield variability, with monsoon rain and maximum temperature being the most significant individual predictors.

These findings highlight the vulnerability of rice production to climatic shifts, particularly changes in monsoon patterns and night-time temperatures. Agricultural policies and adaptation strategies should focus on developing resilient crop varieties and effective water management practices to mitigate the negative impacts of excessive monsoon rains and rising night-time temperatures. The finding reflects a transition period in which technological improvements in agriculture have offset the climatic stress of reduced rainfall and higher temperatures, allowing rice yields to be sustained and even enhanced. However, the long-term sustainability of this trend depends on the implementation of effective climate adaptation strategies, particularly in water management and heat resilience. Grasping the factors that influence its yield is essential for effective policy formulation and sustainable agricultural progress.

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